ROOF-BOLTING THE DELAWARE AQUEDUCT

BY D. H. PLATT

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SUMMARY

Data obtained from on-the-site observations have been compiled to describe the equipment and installation methods used for satisfactory suspension roof support in a large-diameter tunnel.

Experimental roof bolting was undertaken from June 1950 until May 8, 1951, in the East Delaware tunnel, which is part of the Delaware aqueduct in Delaware and Sullivan Counties, N. Y.

Revised suspension-roof-support plans and specifications were prepared during the spring of 1951 by the City of New York Board of Water Supply; these were approved by the State of New York Department of Labor April 13, 1951, and adopted by the City of New York Board of Water Supply on May 8, 1951.

Neither a lost-time injury nor a fatality attributable to roof falls occurred in the East Delaware tunnel from May 8, 1951, to May 20, 1952.

Approximately 124,350 roof bolts have been installed and have satisfactorily supported about 65,187 linear feet of roof, thereby effecting safer working conditions, a tremendous saving in vitally needed steel, and increased efficiency.

INTRODUCTION

In 1950 New York City had a population of 7.9 million, and tremendous quantities of water were vital for its domestic, municipal, and industrial uses. In 1947 the average daily water demand for New York City was 1,160,000,000 gallons; its daily per capita demand was about 147 gallons, each New Yorker consuming 52,232 gallons of water during the year.2/ All of these figures probably will be exceeded in 1952.

The City of New York Board of Water Supply must be able to assure every citizen a constant water supply ample for daily needs. To fulfill this responsibility, well-planned and adequately constructed tunnels and aqueducts have been provided to convey water from reservoirs in the Catskill Mountains to others on the east side of the Hudson River and thence to the city.

Per capita water demand in New York City has increased steadily since the beginning of the century, and the city population is expected to be approximately 8,500,000 by 1960. Water-supply and conveying facilities must be

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2/ Data published by City of New York Board of Water Supply.

planned and constructed to meet expanding needs. The most recent extension of these facilities comprises construction of reservoirs and connecting tunnels; one of the latter, known as the East Delaware tunnel, is discussed in this report. (Fig. 1.)

When complete, the East Delaware tunnel, approximately 25 miles long, will convey water impounded in the Pepacton Reservoir, on the East Branch of the Delaware River, near Downsville, Delaware County, N. Y., through the Catskill Mountains to Rondout Reservoir on Rondout Creek, near Grahamsville, Sullivan County, N. Y., and then through the Delaware aqueduct to the city. (Fig. 2.) Plans and specifications for these facilities have been prepared by the City of New York Board of Water Supply, the final authority for completion standards.

The Walsh Construction Company and B. Perini & Sons, Inc., New York, N. Y., is the contractor; all phases of underground construction are to be completed by this concern.

ACKNOWLEDGMENT

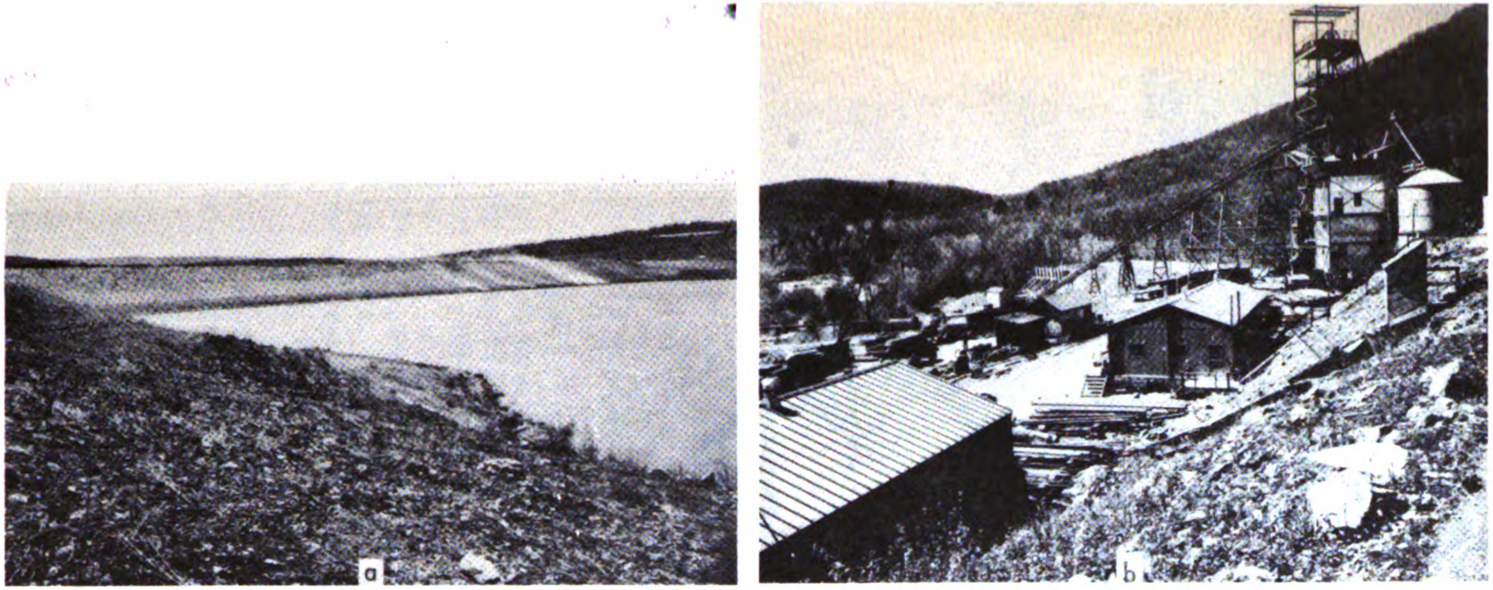
The cooperation and assistance given and the courtesies extended by personnel of the City of New York Board of Water Supply and the contractor are gratefully acknowledged. N. LeRoy Hammond, deputy chief engineer, and William A. Nolan, safety engineer, City of New York Board of Water Supply, and J. S. Macdonald, vice president and general manager; C. F. Kelley, project manager; C. S. Turner, project superintendent; A. J. Allio, project engineer; and J. V. Aspenleiter, safety engineer, Walsh Construction Company and B. Perini & Sons, Inc., gave freely of their time; and their suggestions have contributed toward assembling and correlating pertinent information and data.

Photographs, diagrams, and detail drawings, unless otherwise indicated, have been supplied by the City of New York Board of Water Supply.

TUNNEL DESCRIPTION

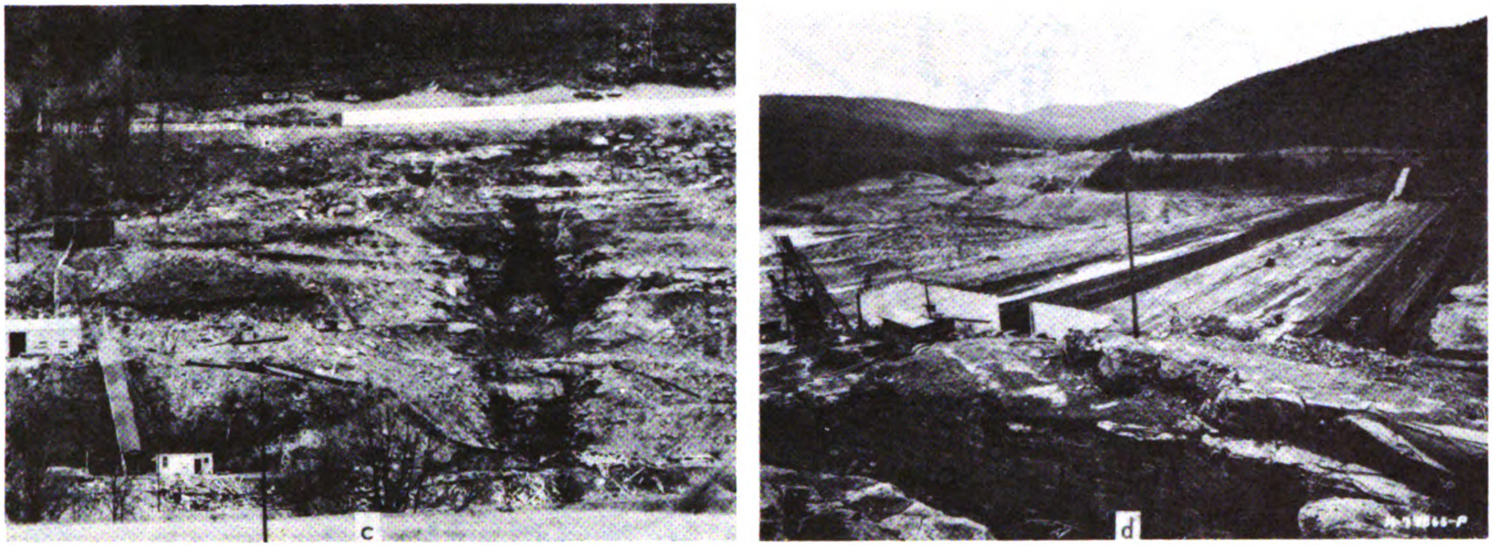
Four contracts are operated in conjunction with the ultimate completion of the tunnel. They are contract 405, inlet tunnel; contract 406, shaft 1; contract 407, shaft 2; and contract 408, outlet tunnel. Shafts 1 and 2 have been sunk on the tunnel line to intercepting elevations. The inlet tunnel and the northwest heading from shaft 1 have been connected, and the southeast heading is being advanced on line and grade. Drifts in both directions from shaft 2 and the outlet tunnel will be advanced on line and grade until connections are made. All headings as driven were approximately 13-1/2 feet in diameter. The finished pressure-type tunnel will be concrete-lined and 11 feet 4 inches in diameter in the clear. The portal of the outlet tunnel is approximately 840 feet and that of the inlet tunnel approximately 1,143 feet above sea level. When the northwest drift from shaft 1 reached a point approximately 12,000 feet from the shaft, it was about 1,680 feet below the surface. The average cover above the completed tunnel will be approximately 1,060 feet.

In the well-coordinated operation cycle, drilling and roof bolting, blasting, scaling, mucking, and track laying follow each other with minimum



Merriman Dam and partly filled Rondout reservoir below outlet, East Delaware tunnel.

Head frame and yard shaft 1.



Portal, inlet tunnel, showing nature of rock formations encountered.

Downsville Dam construction, East Branch Delaware River near inlet, East Delaware tunnel.

Figure 1. - Surface installations and views.

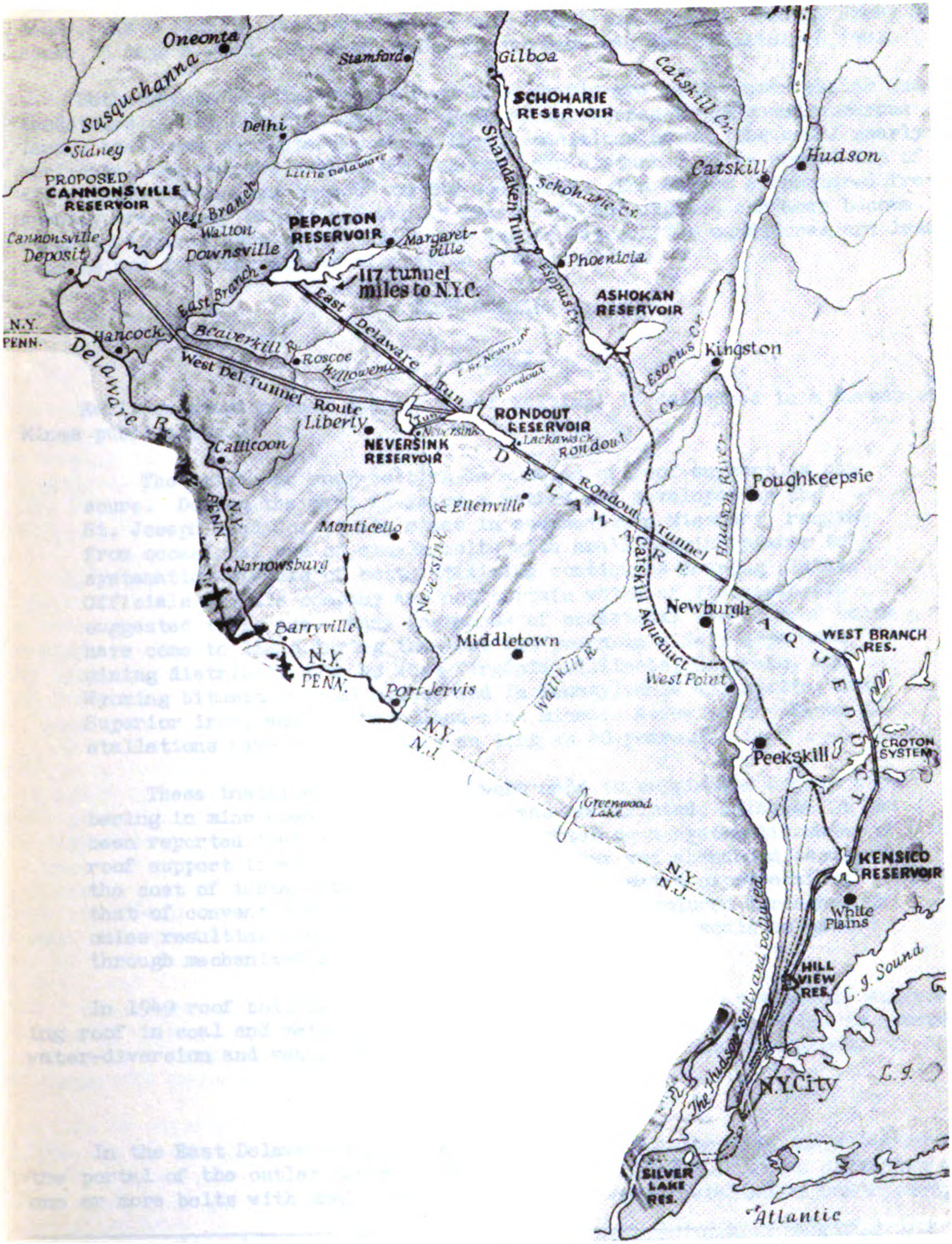


Figure 2. - Area map (partial copy from The New York State Conservationist, June-July 1950, under authority granted by the New York State Conservation Department).

delay. As a result, about six cycles were completed in each heading every 24 hours, 5 days a week. In each cycle the advance was approximately 8 feet.

Both tunnels and the drifts from both shafts are in Devonian shales and sandstones of the Catskill series. Considerable cross-bedding and numerous lenses have been encountered; where these conditions occur, the usual nearly horizontal and uniform stratification has been disturbed. The normal dip of all formations is less than 5° to the southwest. The shales encountered frequently are finely bedded and easily fractured, and exposed surfaces become slightly altered upon contact with air and/or water. The sandstones are less friable and less subject to alteration with exposure.

ROOF BOLTING

History

Early suspension roof support (roof bolting) is described in a Bureau of Mines publication.[3]

> The origin of roof bolting as a means of roof support is obscure. During the past 23 years a method was developed by the St. Joseph Lead Co. at its mines in southeastern Missouri, ranging from occasional use of single bolts with small bearing plates to systematic networks of bolts utilizing continuous bearing plates. Officials of this company are not certain which of its employees suggested their use. Many instances of occasional use of roof bolts have come to light during the past few years in widely separated mining districts, such as West Virginia, Illinois, Colorado, and Wyoming bituminous coal mines, and in Pennsylvania anthracite, Lake Superior iron, and Colorado lead-zinc mines. A few of the known installations have been in place as long as 40 years.
>
> These installations usually were made to supplement wooden timbering in mine openings where space was constricted, although it has been reported that roof bolting was started as a systematic means of roof support in at least three instances but was abandoned because the cost of installation was excessive. The extra expense above that of conventional timbering could not be recaptured through economies resulting from increased efficiency, such as would be gained through mechanized mining.

In 1949 roof bolting attracted widespread interest as a means of suspending roof in coal and metal mines. Roof bolting also has been tried in numerous water-diversion and vehicular tunnels with varying degrees of success.

East Delaware Tunnel

In the East Delaware tunnel, experimental roof bolts were installed near the portal of the outlet tunnel during the summer of 1950. These consisted of one or more bolts with small bearing plates and were installed in restricted, isolated roof areas. They were considered unsatisfactory, and bolting was temporarily discontinued. Some of the factors contributing to the decision to discontinue the experiments follow:

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[3] Thomas, Edward, Roof Bolting in the United States: Bureau of Mines Inf. Circ. 7583, 1950, p. 1.

1. Because of the experimental nature of the work, it was considered desirable to explore all sources of information as to the most satisfactory roof-bolt pattern for large tunnels with nearly circular cross section.

2. Adequate equipment adapted to the particular purpose was lacking.

3. Personnel was inexperienced in the proper manner of installing roof bolts.

4. Neither the City of New York Board of Water Supply nor the State of New York, Department of Labor, Division of Industrial Safety Service, Bureau of Mines, Tunnels, Quarries, and Explosives was satisfied with the caliber of the installations.

However, the merit of suspension roof support was recognized, and plans and specifications were designed and approved for roof bolting in the East Delaware tunnel; in formulating these, pertinent publications and other information pertaining to roof bolting were considered.[4] Safety, roof support of a type not easily dislodged by blasting or by moving equipment, improved ventilation, more clearance, better housekeeping, lower costs, and increased operating efficiency were some of the benefits anticipated with adoption of roof bolting as planned.

The first roof-bolt installation, subsequent to the first approved plans and specifications, was made on September 15, 1950, in contract 408, outlet tunnel. From that date until February 21, 1951, when the writer first observed the work, 1,443 channels had been installed in the outlet tunnel; many of these were supported by two bolts.

These installations were confined to four separate roof areas, 226, 449, 238, and 295 feet in length and located, respectively, 2,694, 4,060, 5,441, and 7,053 feet from the portal to the midpoint of the sections. There were 242, 419, 227, and 235 9-foot steel railroad ties, each supported by two roof bolts, in the respective sections in positions parallel to the tunnel direction. About 150 4-foot channels, supported by 1 roof bolt, were installed within 1,500 feet of the portal, and about 170 9-foot steel railroad ties with 2 bolts were installed at isolated locations between the sections.

Bolts designed for wedge-type anchorage were made in the contractor's shops. They were 1-1/2 and 1-1/4 inches in diameter and 6 feet long. Each bolt had approximately 6 inches of cut thread on one end and a slot 9 inches long in the opposite end. Wedges were 1-1/2 and 1-1/4 inches wide, 3/8 inch thick, and had a 6-inch tapered length.

Other installations near the outlet tunnel portal consisted of 6- by 1/4-inch channels, 3 feet 11-1/2 inches long with a 1-9/16-inch-diameter hole burned in the center. These were secured to the roof by placing them over installed slit-rod-and-wedge-type bolts 1-1/2 inches in diameter and 6 feet long, using unfinished hex nuts; neither washers nor bearing plates were placed between the channels and the nuts. Wooden blocks and/or wedges were used to effect continuous contact between channels and the roof irregularities. Bolts were spaced on approximate 6-foot centers in the direction of the tunnel and across the roof. Channels were placed nearly parallel to the tunnel direction.

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[4] Thomas, Edward, Barry, A. J., and Metcalfe, Arthur, Suspension Roof Support. Progress Report 1: Bureau of Mines Inf. Circ. 7533, 1949, 13 pp.

Subsequently, the single-bolt channel installations were discontinued in favor of an adaptation of the roof-bolting specifications used in the United States Department of the Interior, Bureau of Reclamation, West Canal, Frenchman Hill tunnel. Nine-foot steel tunnel ties,5/ 5-1/2 inches wide with a deformed center section 1 inch deep and with two 4-1/2- by 2-inch slotted openings burned approximately 10 inches from each end, were substituted for channels. Unfinished, 3- by 4-inch steel washers 1/2 inch thick with a 1-3/4-inch-diameter hole in the center served as bearing plates.

The resulting installation pattern differed from that used in other mining operations. When tunnel ties were finally placed, they were roughly parallel to the tunnel center line. Roof bolts supporting the ties were alternated on about 7- and 5-1/2-foot centers; the longer spacing was between the bolts in each tie. Ends of ties were approximately 3-1/2 feet apart. In each 9-foot tunnel section, four ties were installed on approximate 30-inch centers across the tunnel roof.

A track-mounted flatcar, approximately 7 feet long and 4 feet wide with a deck approximately 2 feet above the rail, was used to mount one pneumatic, percussion drifter upon a 6-foot column with a crossbar and saddle. The drill carriage was 6 feet long and provided with an automatic feed. At any set-up, the truck was clamped to the rails, and four holes were drilled radially across the back, 30 inches apart. Holes were collared and drilled wet.

Only one drill change was necessary to attain the desired hole depth of 5 feet 9 inches. The starter bit was 1-3/4 inches in diameter and the finishing bit 1-5/8 inches in diameter. The diameters of holes drilled for roof bolts were controlled by available bit diameters. Roof bolts 1-1/2 and 1-1/4 inches in diameter were used for these installations.

Upon completion of four radiating holes, roof bolts were driven to a secure position with the drifter machine, using a drill rod and a threadless-type dolly. Impact was upon the chamfered ends of the bolts. Tunnel ties were placed over each roof bolt successively and held with the drifter machine and a drill rod with a saddle-shaped fork to conform with the shape of the tie until the washer was placed and the nut partly threaded. Nuts were finally tightened with an impact wrench. From a new position of the flatcar, holes were drilled through the slotted openings in the opposite ends of the ties. Washers were applied and nuts tightened as before.

It is reported that torque wrenches were used regularly to check the tightness of the bolts, and readings usually indicated at least 450 foot-pounds torque. When an area 50 to 100 feet had been bolted in this manner, that section of the roof was gunited in accordance with installation specifications.

5/ Steel shape as manufactured by Bethlehem Steel Corp. designed originally for use as ties for the support of mine track.

This procedure precluded roof bolting in the headings. Consequently, desired protection was not afforded, because experience in the support of mine roofs has shown that roof-bolting results are best when installations are made before appreciable strata flections develop, which result in strata and laminae separations. In this manner, the original strength is maintained, and weak roof strata can be consolidated to form relatively strong beams. Roof bolts properly installed in headings as soon as possible after blasting can prevent roof falls and continuous scaling, and the possible necessity of installing other types of roof support is lessened. Where installed in the East Delaware tunnel, steel sets were placed on centers as necessitated by conditions.

Installation Methods and Techniques

Bureau of Mines recommendations made after the February inspection of installations resulted in a revision of roof-bolting specifications. The revised specifications were approved for use in the East Delaware tunnel by the State of New York Department of Labor in its resolutions of April 13, 1951, and by the City of New York Board of Water Supply in its letter of May 8, 1951.

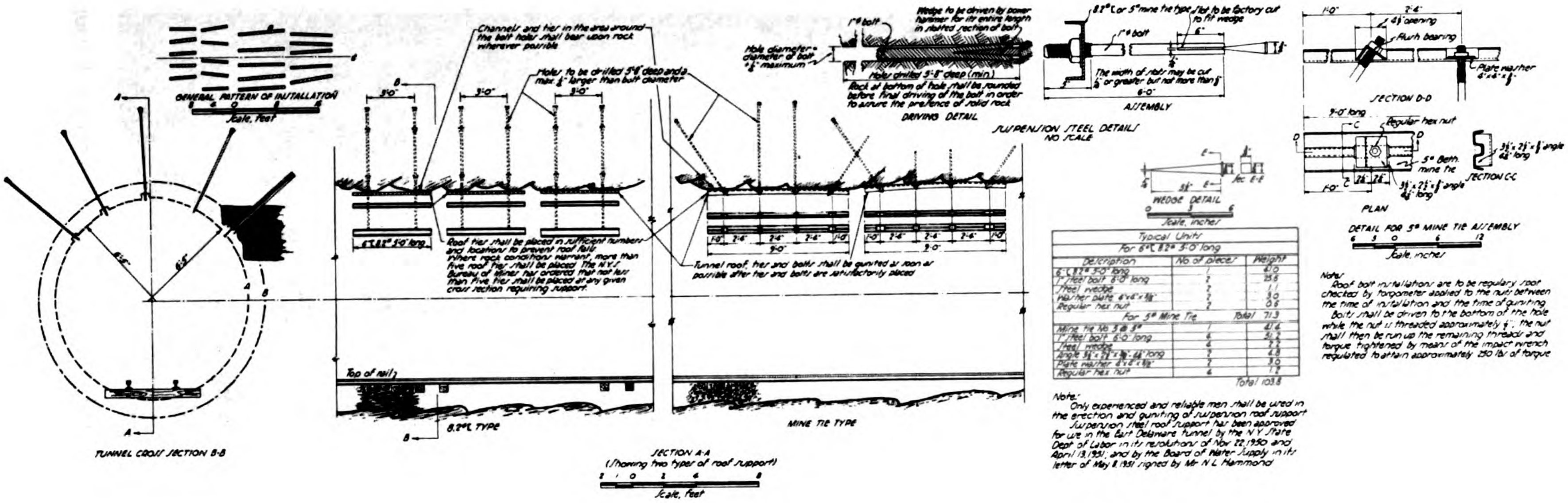
The new specifications provided for slit-rod-and-wedge-type bolts, 6 feet long, 1-inch-diameter nominal (29/32 inch), with 5 inches of rolled thread on one end and a 6- by 1- by 1/16-inch cut slot in the opposite end. Six-inch channels, 8.2 pounds per foot and 5 feet long, and 9-foot No. 5 tunnel ties were specified for use in conjunction with the roof bolts. Details showing installation patterns, specifications of accessories, diameter and length of holes drilled for roof bolts, and the weights of each unit are shown in figure 3.

With the advent of the revised specifications, the contractor made plans to install roof bolts during the face drilling phase of each operation cycle.

Each heading was drilled using a track-mounted drill jumbo (fig. 4) designed by the contractor, with six hydraulic jibs, three on the upper deck and three below. Upon each jib and its attached boom was mounted a pneumatic, percussion drifter, with automatic feed, hole spotter, and double-action piston motor; it was lubricated from a line oiler. The over-all length of the jumbo, exclusive of the drill booms, was approximately 31 feet, the width of the main deck was about 4 feet 9 inches, and, when wing platforms were elevated, the width was approximately 11 feet 6 inches. The height to the upper deck above the rail was about 6-1/2 feet.

On the jumbos used in the drifts from shaft 2, contract 407, cross-arm assemblies, consisting of horizontal columns or bars 4 inches in diameter and about 10 feet long, were welded to tubular uprights. They paralleled the longitudinal axis of the jumbo and were about 18 inches above each side of the upper deck. The forward ends of the cross arms were approximately 4-1/2 and 15-1/2 feet, respectively, to the rear of the hydraulic jibs and the forward end of the jumbo. (Fig. 5.)

Two drifters, mounted on saddles clamped to the cross arms, were used for roof bolting; the drifters on the same cross bar were operated as a unit.


GENERAL PATTERN OF INSTALLATION
Scale, feet
TUNNEL CROSS SECTION B-B
A
B
6'-6"
Channels and ties in the area around the bolt holes shall bear upon rock wherever possible
Holes to be drilled 5'-8" deep and a max. 1/8" larger than bolt diameter
3'-0"
6" ⊏ 8.2# 5'-0" long
Roof ties shall be placed in sufficient numbers and locations to prevent roof falls. Where rock conditions warrant, more than five roof ties shall be placed. The N.Y.S. Bureau of Mines has ordered that not less than five ties shall be placed at any given cross section requiring support.
Tunnel roof, ties and bolts shall be gunited as soon as possible after ties and bolts are satisfactorily placed
1'-0"
2'-4"
9'-0"
Top of rails
8.2# ⊏ TYPE
MINE TIE TYPE
SECTION A-A
(Showing two types of roof support)
Scale, feet
1" ⌀ bolt
Hole diameter = diameter of bolt + 1/8" maximum
Wedge to be driven by power hammer for its entire length in slotted section of bolt
Holes drilled 5'-8" deep (min)
Rock at bottom of hole shall be sounded before final driving of the bolt in order to assure the presence of solid rock
DRIVING DETAIL
8.2# ⊏ or 5# mine tie type
Slot to be factory cut to fit wedge
1" ⌀ bolt
6"
The width of slots may be cut 1/8" or greater but not more than 3/16"
6'-0"
ASSEMBLY
SUSPENSION STEEL DETAILS
NO SCALE
WEDGE DETAIL
Sec E-E
Scale, inches
4 1/2" opening
Flush bearing
Plate washer 4"x4"x3/8"
SECTION D-D
9'-0" long
Regular hex nut
5# Beth. mine tie
3 1/2" x 2 1/2" x 5/16" angle 4 1/2" long
SECTION C-C
PLAN
DETAIL FOR 5# MINE TIE ASSEMBLY
Scale, inches

Typical Units		
For 6" ⊏ 8.2# 3'-0" long		
Description	No. of pieces	Weight
6" ⊏ 8.2# 3'-0" long	1	41.0
1" steel bolt 6'-0" long	2	25.6
Steel wedge	2	1.1
Washer plate 4"x4"x3/8"	2	3.0
Regular hex nut	2	0.6
For 5# Mine Tie	Total	71.3
Mine tie No. 5 @ 5#	1	41.6
1" steel bolt 6'-0" long	4	51.2
Steel wedge	4	2.2
Angle 3 1/2"x2 1/2"x5/16"-4 1/2" long	2	4.8
Plate washer 4"x4"x3/8"	2	3.0
Regular hex nut	4	1.2
	Total	103.8

Note:
Only experienced and reliable men shall be used in the erection and guniting of suspension roof support.
Suspension steel roof support has been approved for use in the East Delaware tunnel by the N.Y. State Dept. of Labor in its resolutions of Nov. 22, 1950 and April 13, 1951; and by the Board of Water Supply in its letter of May 8, 1951 signed by Mr. N. L. Hammond.

Notes:
Roof bolt installations are to be regularly spot checked by torquemeter applied to the nuts between the time of installation and the time of guniting.
Bolts shall be driven to the bottom of the hole while the nut is threaded approximately 1/4"; the nut shall then be run up the remaining threads and torque tightened by means of the impact wrench regulated to attain approximately 250 lbs. of torque.

Figure 3. - East Delaware tunnel, suspension-roof-support specifications.

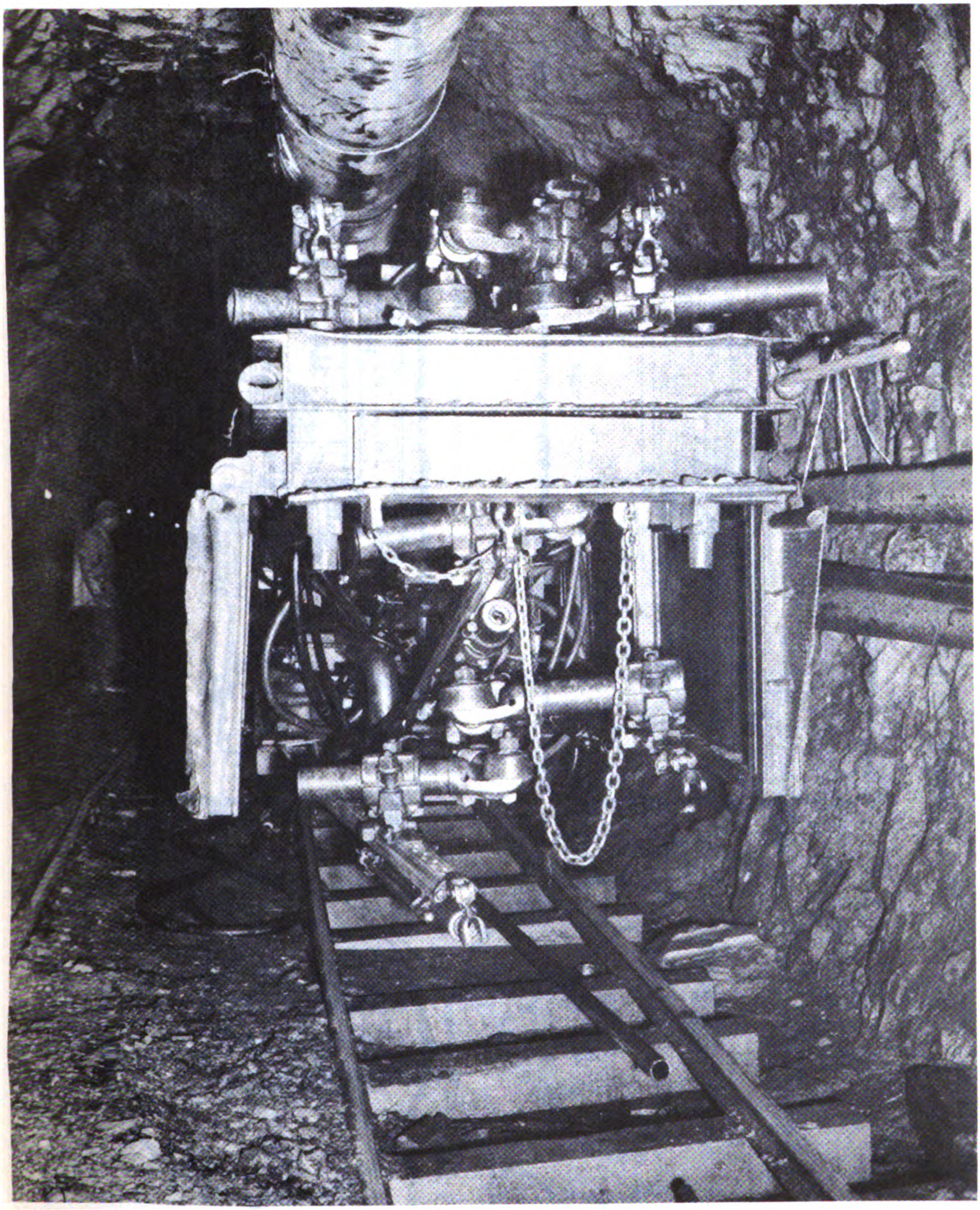


Figure 4. - Front end of jumbo, showing drill assembly.

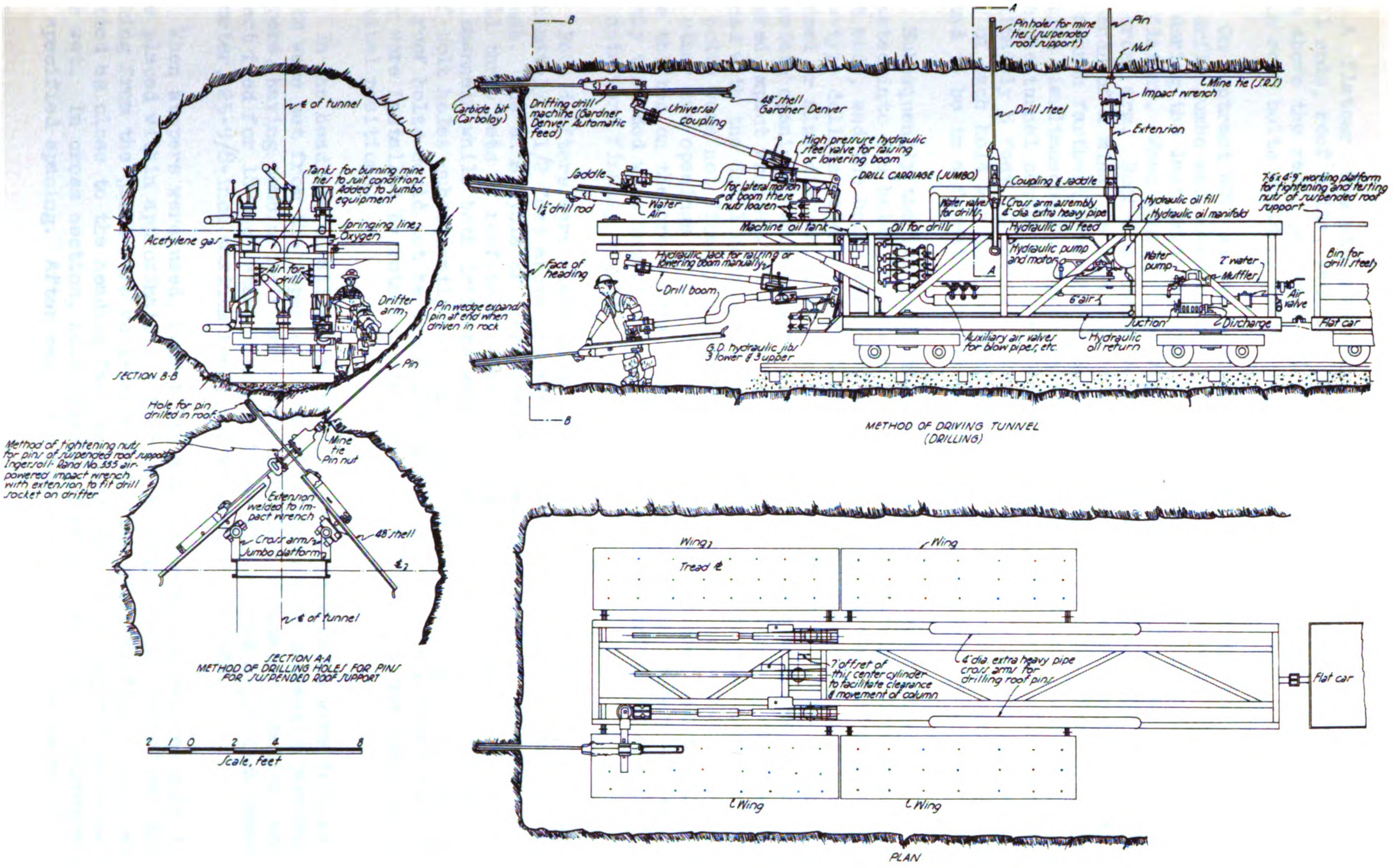

℄ of tunnel
Tanks for burning mine ties to suit conditions. Added to jumbo equipment
Springing line
Oxygen
Acetylene gas
Air for drills
Drifter arm
Pin wedge expands pin at end when driven in rock
Pin
SECTION B-B
Hole for pin drilled in roof
Method of tightening nuts for pins of suspended roof support. Ingersoll-Rand No. 355 air-powered impact wrench with extension to fit drill socket on drifter
Mine tie
Pin nut
Extension welded to impact wrench
Cross arms
Jumbo platform
48" shell
℄ of tunnel
SECTION A-A
METHOD OF DRILLING HOLES FOR PINS FOR SUSPENDED ROOF SUPPORT
2 1 0 2 4 8
Scale, feet
B
B
A
A
Carbide bit (Carboloy)
Drifting drill machine (Gardner Denver Automatic feed)
48" shell Gardner Denver
Universal coupling
High pressure hydraulic steel valve for raising or lowering boom
Saddle
For lateral motion of boom these nuts loosen
1¼" drill rod
Water
Air
DRILL CARRIAGE (JUMBO)
Machine oil tank
Face of heading
Hydraulic jack for raising or lowering boom manually
Drill boom
G.D. hydraulic jibs 3 lower & 3 upper
Pin holes for mine ties (suspended roof support)
Drill steel
Coupling & saddle
Water valve for drills
Cross arm assembly 4" dia. extra heavy pipe
Oil for drills
Hydraulic oil feed
Hydraulic pump and motor
Auxiliary air valves for blow pipes, etc.
6" air
Pin
Nut
℄ Mine tie (S.R.S.)
Impact wrench
Extension
Hydraulic oil fill
Hydraulic oil manifold
Water pump
2" water
Muffler
Suction
Hydraulic oil return
Discharge
Air valve
7'-6" x 4'-9" working platform for tightening and testing nuts of suspended roof support
Bin for drill steel
Flat car
METHOD OF DRIVING TUNNEL (DRILLING)
Wing
Wing
Tread ℄
7" offset of this center cylinder to facilitate clearance & movement of column
4" dia. extra heavy pipe cross arms for drilling roof pins
Flat car
℄ Wing
℄ Wing
PLAN

Figure 5. - Drill-carriage jumbo and drilling detail.

A flatcar was attached to the rear of the jumbo and was used to carry drill rods, roof bolts, washers, channels, and ties. An upper deck, 6-1/2 feet above the rail, provided a 7-foot 6-inch by 4-foot 9-inch platform, from which roof bolts could be tested and retightened.

On contract 407, at the beginning of a drilling cycle and as quickly as the drill jumbo was moved to the face, the roof-bolt crew retightened bolts set during the last drilling cycle, working from the upper decks of the jumbo and flatcar. When roof bolting was begun, the two drifters were mounted on one cross arm. Roof-bolt holes were spotted to coincide with openings nearest the ends of a mine tie or those in a 6-inch channel; holes to be drilled on the haunch farthest from the cross arm were spotted first. Two holes were drilled simultaneously, approximately 40° from horizontal and about 5-1/2 feet from the tunnel center line, and terminated when they attained a depth of approximately 5 feet 10 inches. All collaring and drilling were done wet. The back of each hole was sounded manually by tapping it with a roof bolt because it had to be in a formation solid enough to anchor the wedge satisfactorily.

Subsequently the two roof bolts, with wedges placed in the slots, were inserted into the holes, nuts were threaded approximately 1/2 inch from the bolt ends, and the bolts were driven to security with the drifters and threadless-type dollies welded to short drill rods. The nuts were then removed, the channel or mine tie was placed in position with the roof bolts through the appropriate openings, washers were placed, and nuts were tightened using an air-powered impact wrench with an extension to fit a drill chuck, which was positioned with the drill carriage. If mine ties were used, the nuts on the first two bolts were not finally tightened until the center holes had been drilled. The other two openings in the tie were used as a template, and the drifters were shifted on the cross arms accordingly. Bolts with washers and the nuts partly threaded were inserted into sounded holes and driven to security, and all nuts were finally tightened.

Both drifters were elevated to permit drilling the next set of holes, approximately 2-1/2 feet above and about in line with those drilled over the haunch. The same cycle of operations then was repeated. It was feasible to drill three sets of roof-bolt holes, set the roof bolts, and place and secure the channels while both drifters were on one cross arm. Two other sets of roof-bolt holes subsequently were drilled from the opposite cross arm, but the roof bolts could not be installed in the immediate face area; however, they were installed by rotating the three top drifters on the jumbo to nearly vertical positions.

In the headings on all other projects, roof-bolt holes were drilled, and bolts were set from the upper decks of the jumbos with pneumatic percussion stopers, having combined air and water throttles, automatic rotation, and direct feed for 18-inch steel change. These stopers had 2-3/4-inch hammer diameter, 25-5/8-inch maximum feed, and weighed 100 pounds.

When stopers were used, roof bolts and supported channels or mine ties were placed within approximately 1 foot of a heading face; therefore, drillers working from the jumbo were well-protected. The first roof-bolt holes were spotted as close to the heading face as possible; collaring and drilling were done wet. In cross section, holes were drilled in practical conformance with the specified spacing. After each hole had been drilled to a depth of approximately 5 feet 10 inches and the back of the hole had been tested by manually tapping it with a roof bolt, a roof bolt with its wedge was inserted into the hole and driven to security with a threadless-type dolly on a section of drill rod in the stoper chuck. Subsequently either a channel or a tunnel tie was placed over the bolt with a bearing washer and nut to hold it temporarily until the roof-bolt hole at its opposite end was drilled through the opening. The intermediate openings in the tunnel-tie section served as templates through which the other holes were drilled. Bolts then were driven to security, washers were placed, and nuts were tightened with hand-held pneumatic-impact wrenches. A second stoper usually was employed to drill the second and succeeding roof-bolt holes for each supporting unit. In this manner, one stoper, at the forward end of the jumbo, drilled all holes necessary and drove the roof bolts to permit placing either a channel or a mine tie without undue interference with the drillers working on the jumbo. (Figs. 6, 7, 8, 9, 10, and 11.)

Frequent spot checks have been made of bolt tensions with torque meters; bolt tensions usually have been found to be between 175 and 250 foot-pounds torque.

Gunite, approximately 3/4 inch thick, was applied to all bolted roof sections and to the haunches as frequently as heading advance necessitated and at such times as guniting would not interfere with normal operation cycles. Gunite appears to check slaking, which results when shales and sandstones are exposed to air and moisture; it thus prevents sloughing and minor roof falls that would otherwise occur between roof bolts. (Figs. 12, 13 and 14.)

COMPARATIVE DATA

Figure 15 is a tabulation based upon total progress to May 20, 1952, approximately 1 year after the final plans and specifications were approved and adopted. It shows the advance, linear feet of roof supported by roof bolts, number of roof bolts installed, linear feet of roof supported by steel sets (figs. 16 and 17), linear feet of unsupported roof, totals, and appropriate percentages.

Approximate data pertaining to weights of materials and the man-hours required to install the respective types of roof support in typical 100-foot tunnel sections are shown in figure 18.

SAFETY

All contracts operate three shifts per day, 5 days per week. Approximately 464,000 man-hours were worked during the year following May 8, 1951, when the final plans and specifications for roof support were adopted. Where suspension roof support was used, not one fatality occurred attributable to roof falls - the mining industry's No. 1 killer; significantly, there was not a lost-time accident from this cause.

OTHER ADVANTAGES DERIVED FROM ROOF BOLTING

The various phases of concreting will be undertaken when the headings have been connected. Before the arch is poured in sections of the tunnel

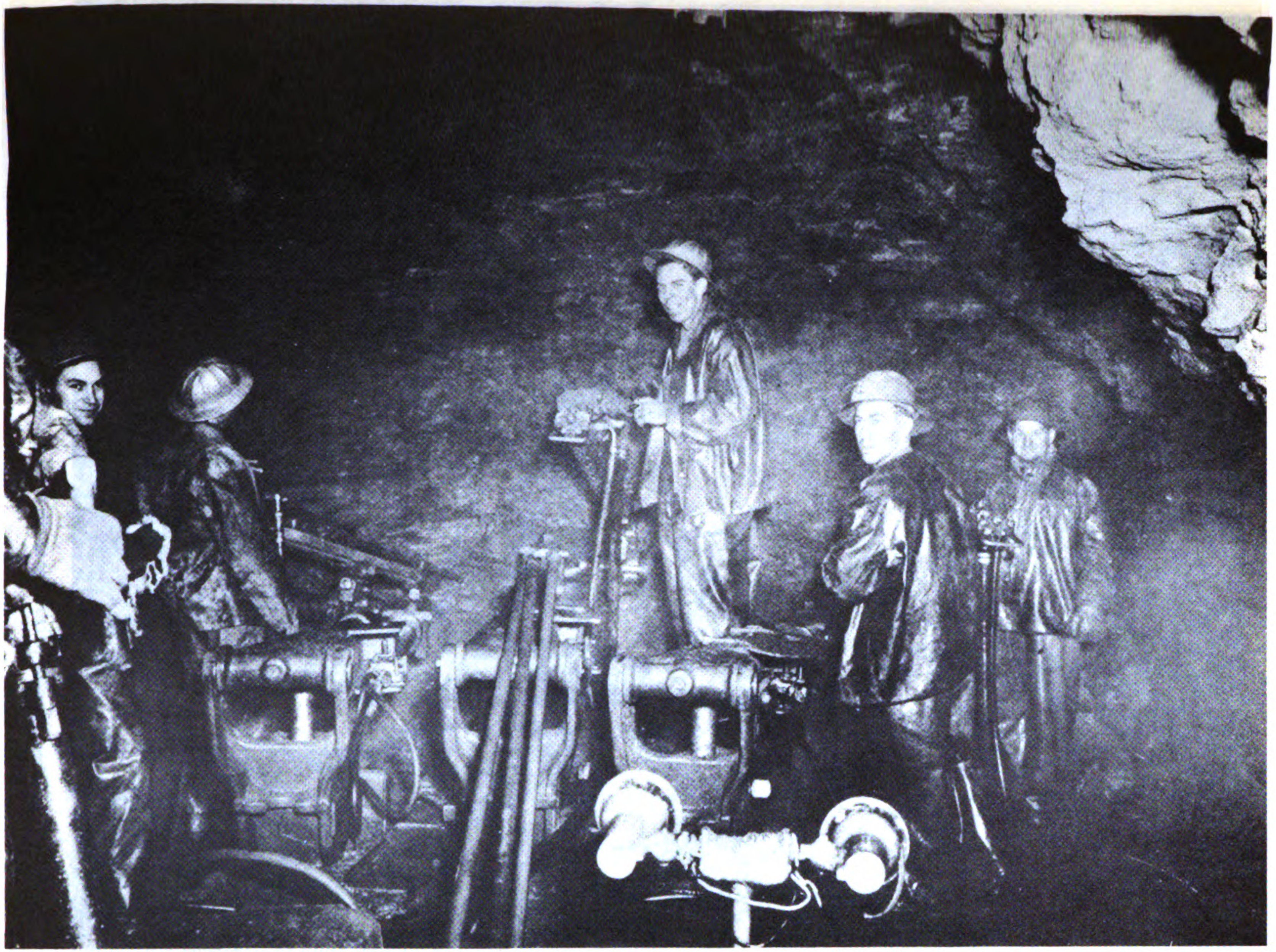


Figure 6. - Drill crew on top deck of jumbo.

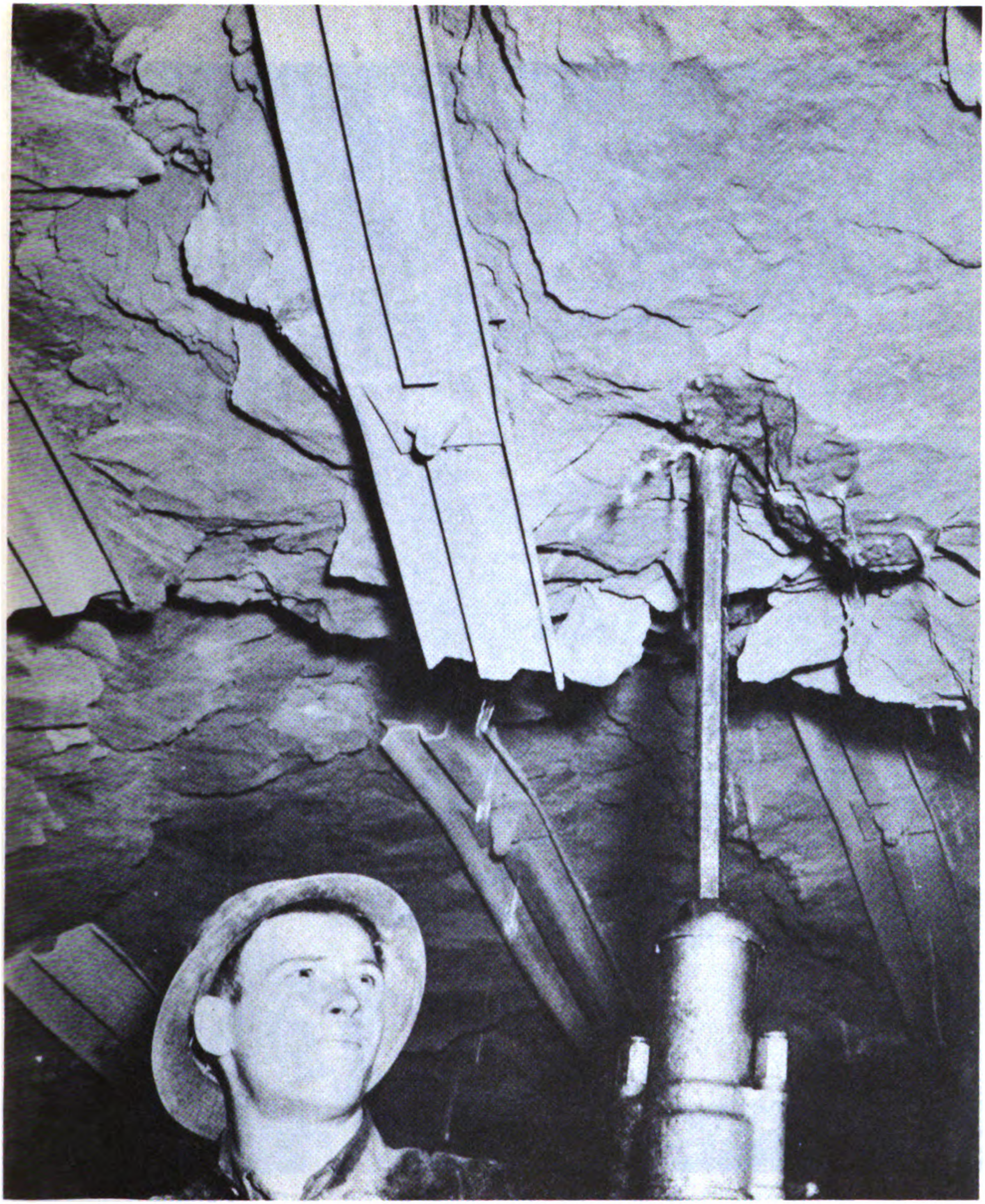


Figure 7. - Collaring a roof-bolt hole with stoper drill, showing water applied during operation.

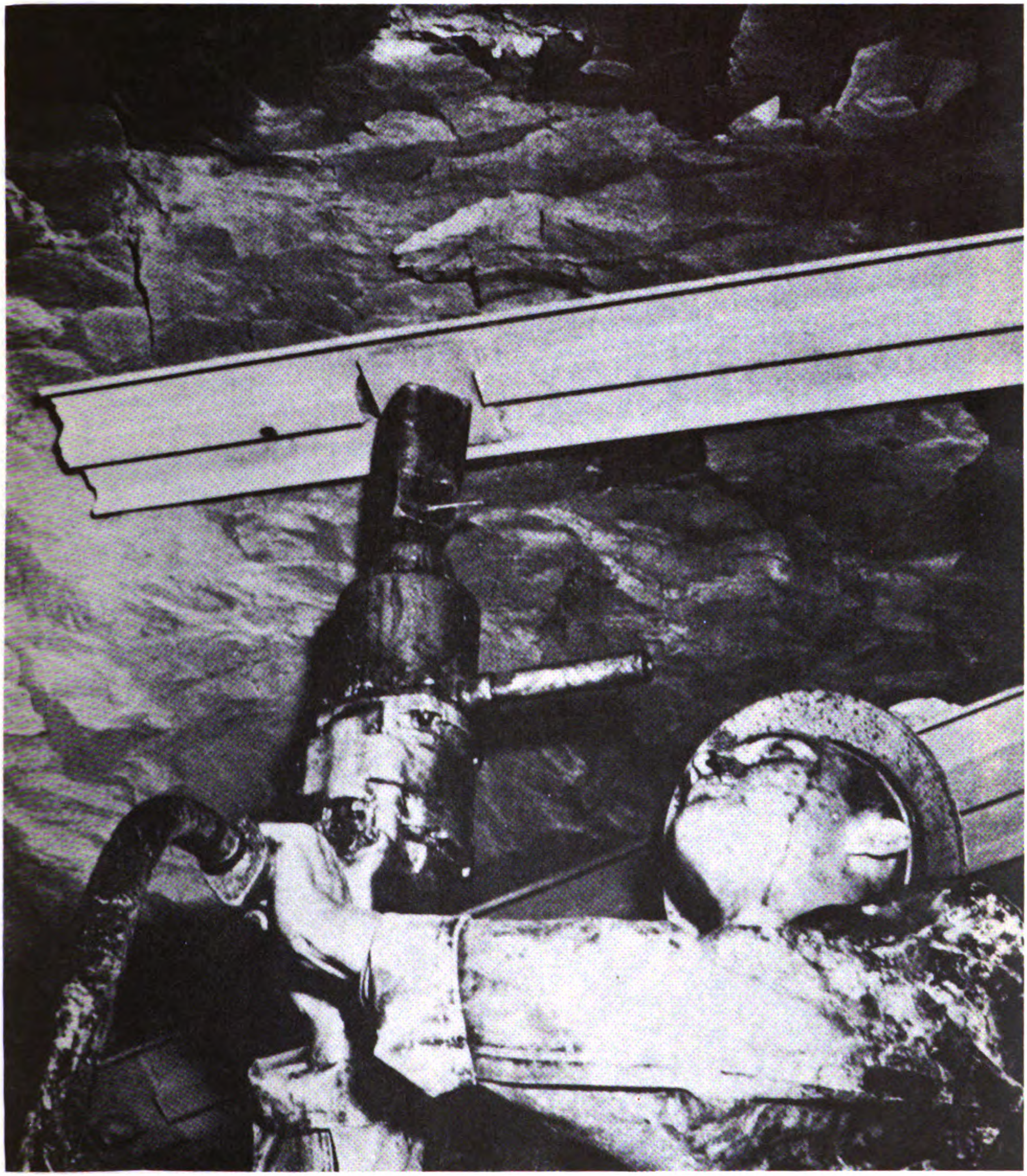


Figure 8. - Tightening nut on roof bolt with air-powered impact wrench.

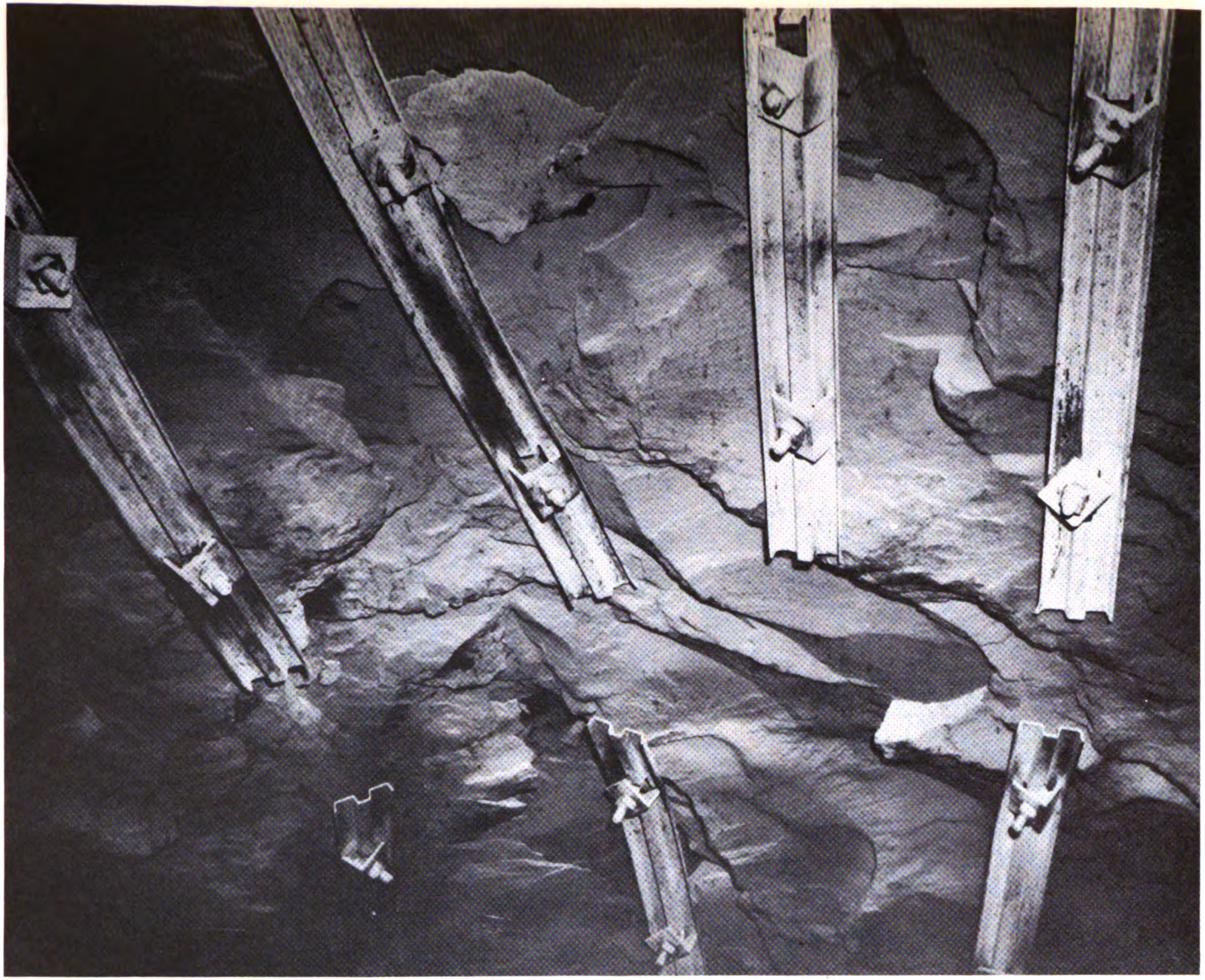


Figure 9. - Typical suspension roof support.

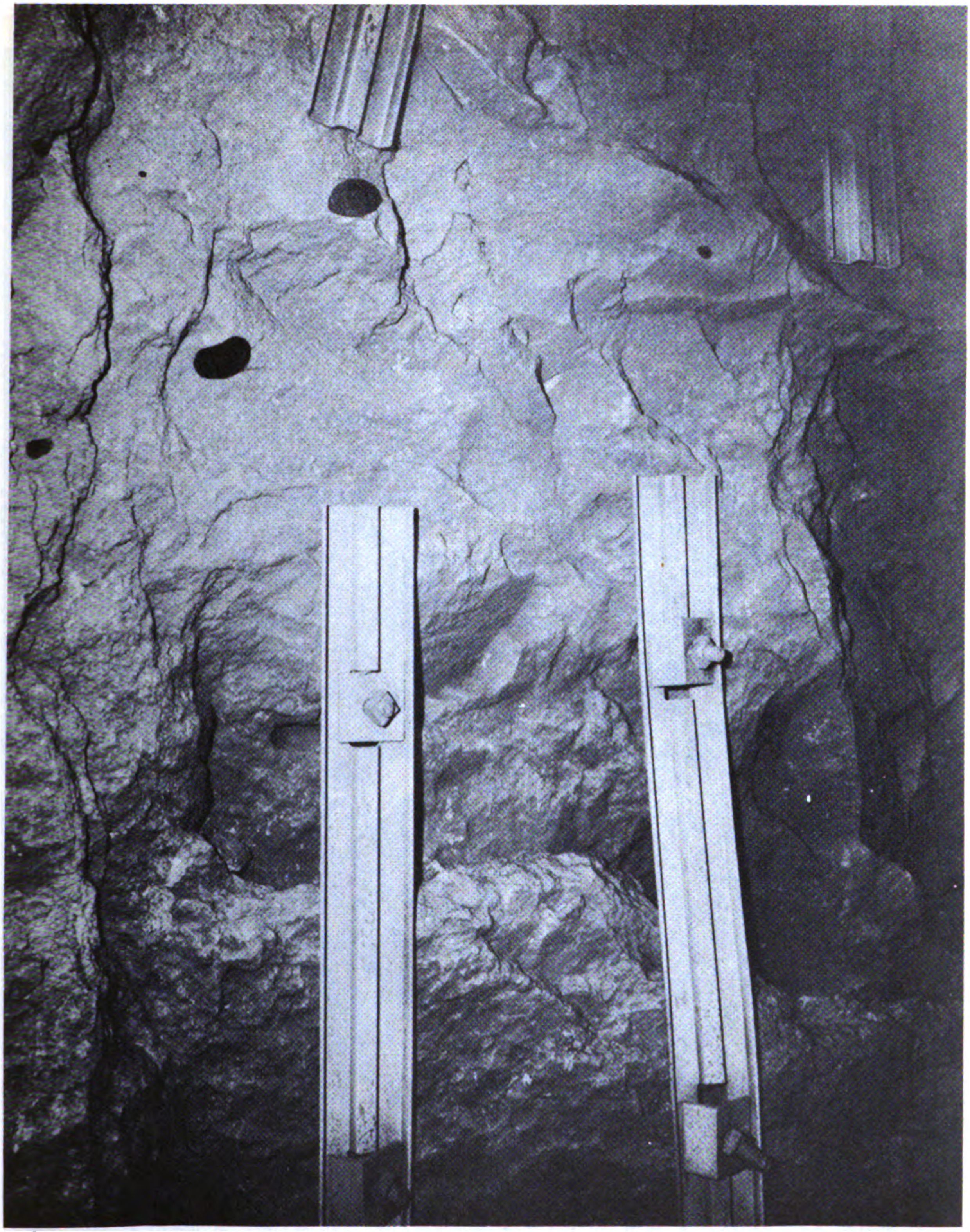


Figure 10. - Typical roof-bolt installation, showing use of angle and flat washers.

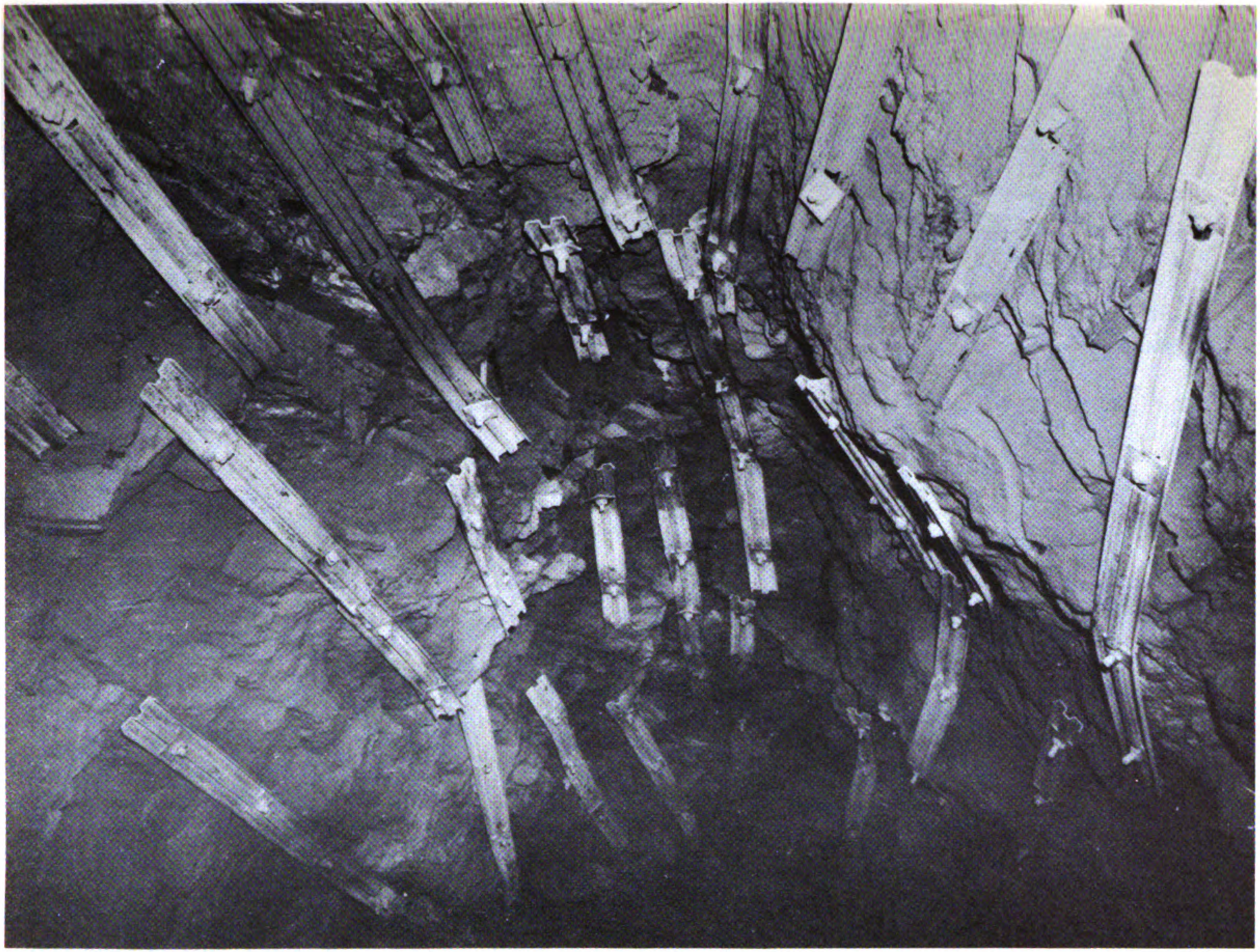


Figure 11. - Typical bolted roof section, showing stratified nature of rock and placement of mine ties nearly parallel to tunnel direction.

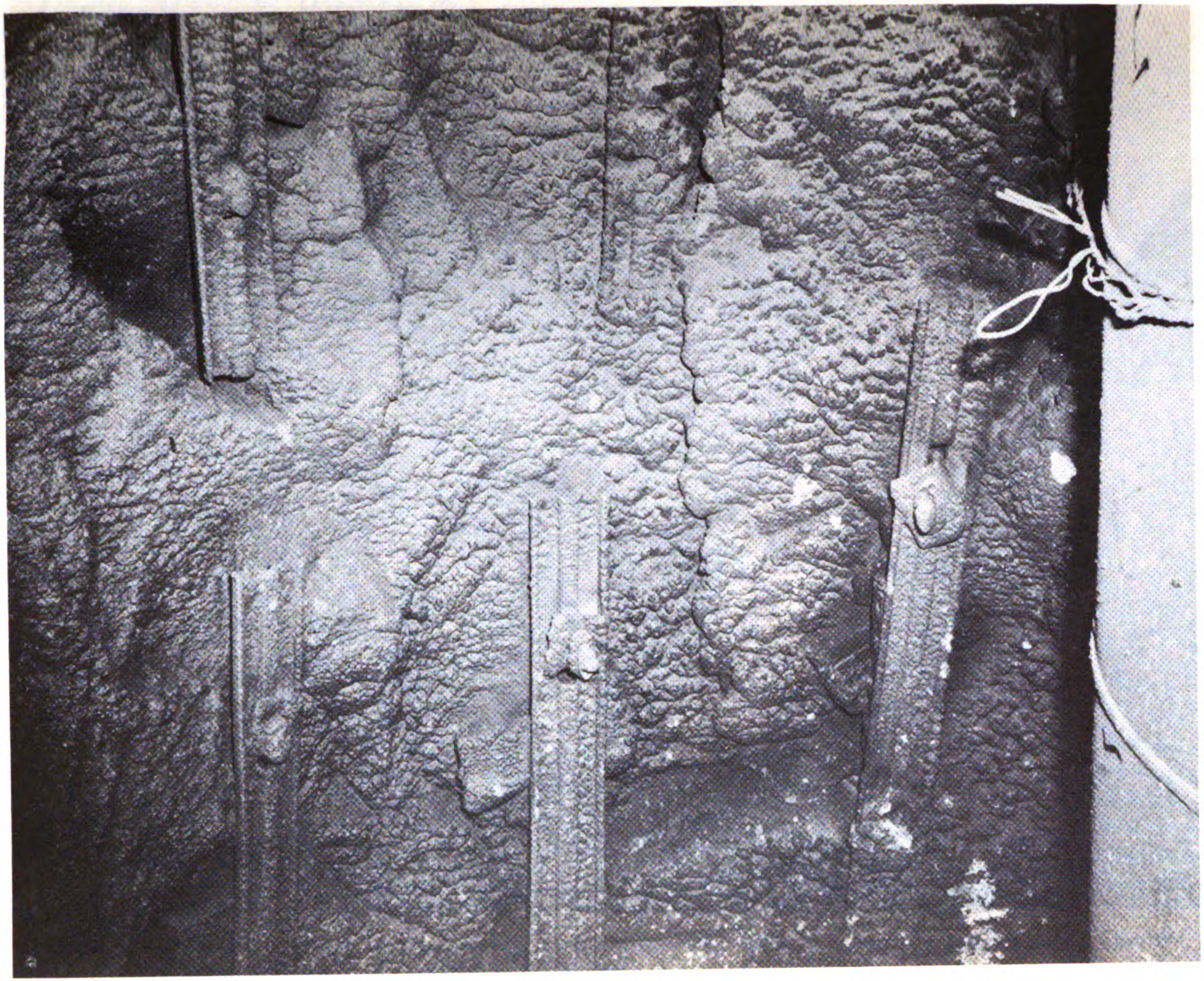


Figure 12. - Typical bolted roof section after guniting.

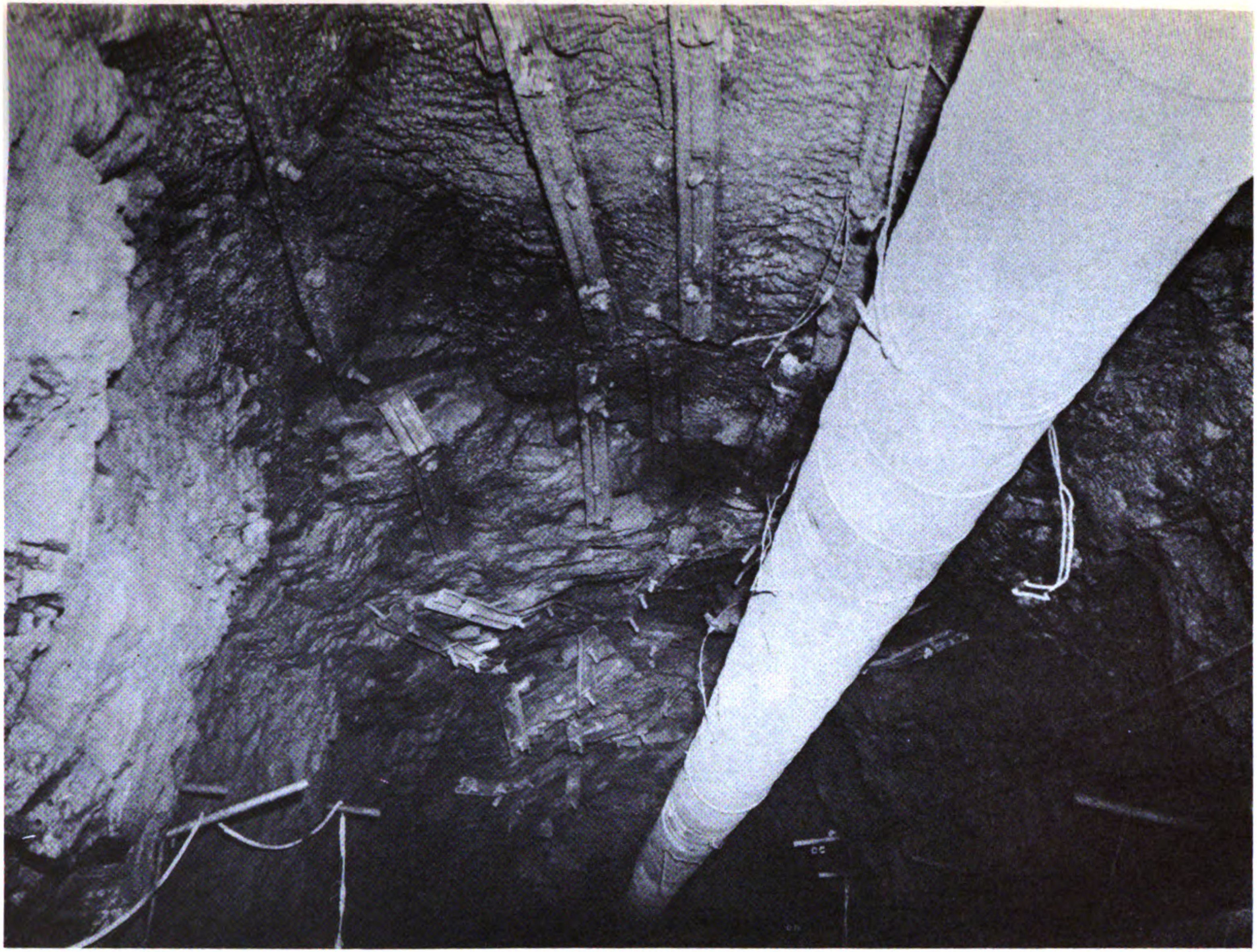


Figure 13. - Typical bolted roof section showing gunite application upper foreground, ungunited section beyond, and ventilation pipe suspended from roof bolts.

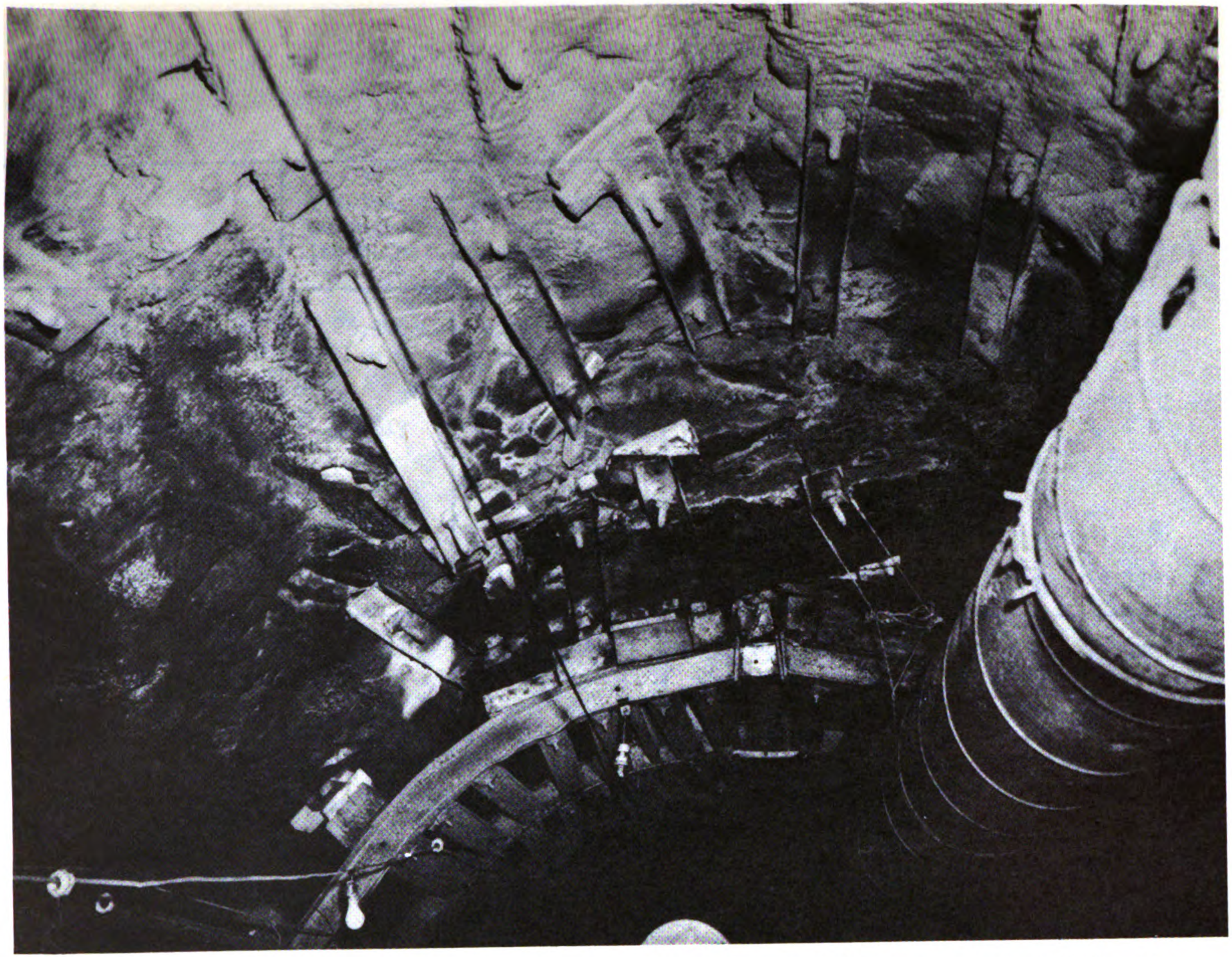


Figure 14. - Typical roof section showing steel set and roof-bolt support, with gunite applied to bolted section.

	Total advance, linear feet	Roof supported by roof bolts, linear feet	Number of roof bolts installed	Roof supported by steel sets, linear feet	Unsupported roof, linear feet
Inlet tunnel	25,305	5,108	10,158	12,964	7,233
Shaft 1:					
Both headings	33,513	26,955	46,660	6,558	0
Shaft 2:					
Both headings	27,958	21,220	46,584	6,738	0
Outlet tunnel	26,260	11,904	20,948	10,017	4,339
Total	113,036	65,187	124,350	36,277	11,572
Percent	100	57.7	-	32.1	10.2

Figure 15. - Comparative data - progress to May 20, 1952.

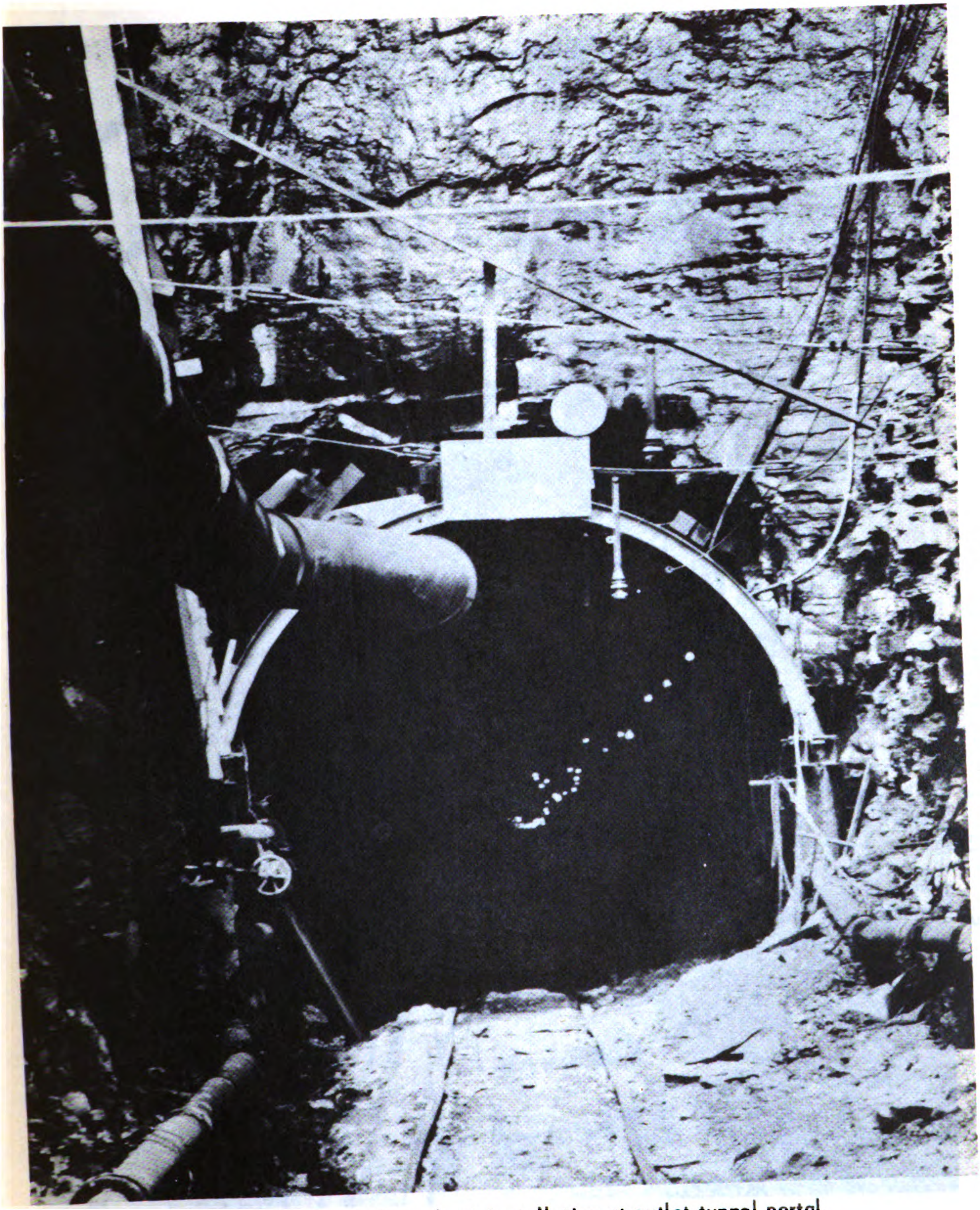


Figure 16. - Typical steel-set installation at outlet tunnel portal.

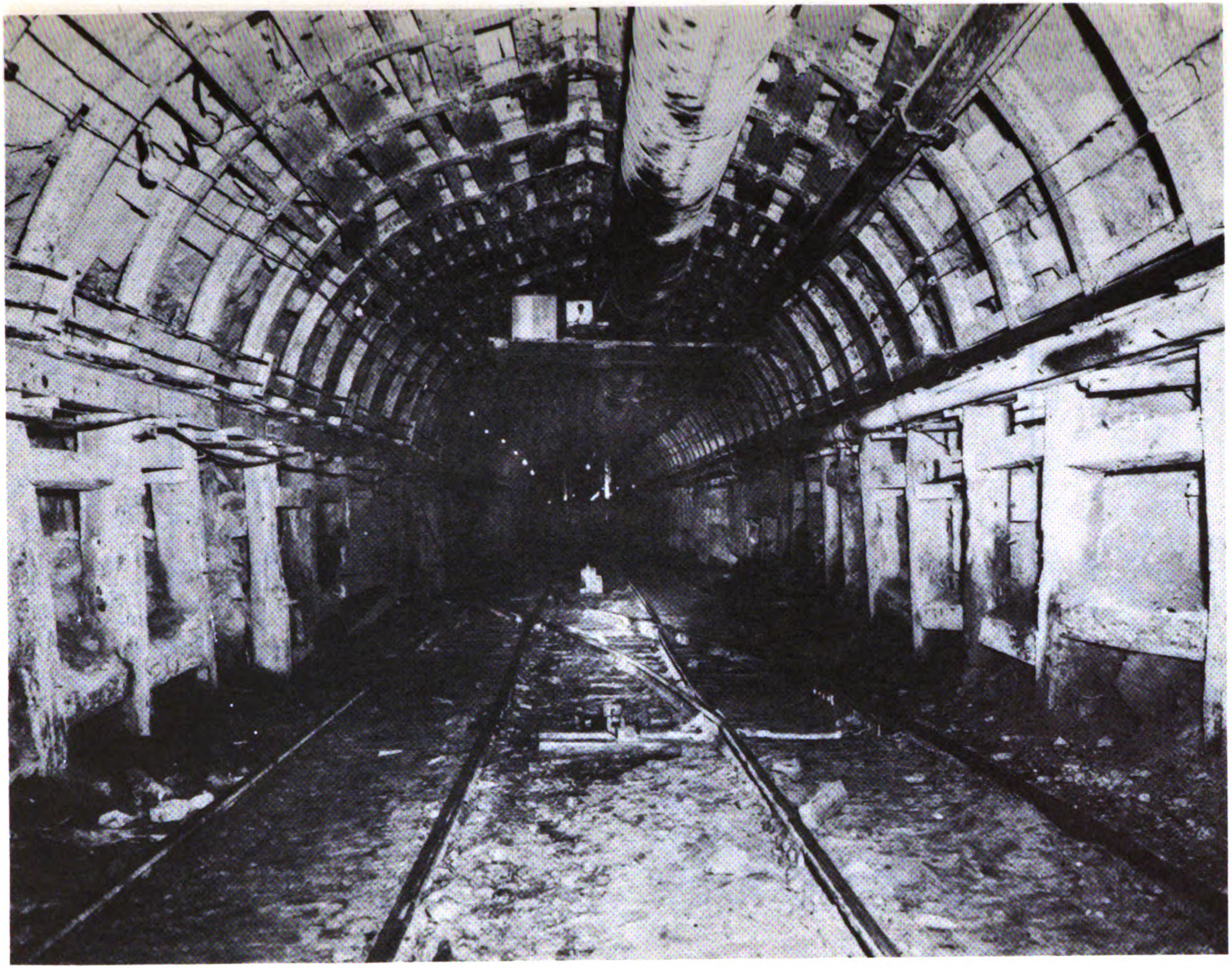


Figure 17. - Typical steel-set installation at side track in tunnel.

	Roof bolts and accessory materials	Rib-type steel sets with lagging
Material weight (pounds)	5,000	34,500
Man-hours for installation ...	112	125
Percent of installation completed during drilling cycles	100	25

Figure 18. - Approximate material weights and the man-hours required to install respective types of roof support in typical 100-foot tunnel sections.

supported by rib steel sets, steel lagging between the sets and all loose roof material above it must be removed; this is a potentially hazardous undertaking. In sections where roof bolts have been installed, there will be very little if any loose roof rock, and workers will have excellent overhead protection. Where roof bolts have been used, an estimated saving of approximately 1/2 cubic yard of concrete in place will be possible for every foot of arch section poured.

Time studies were not made; however, whether surface or underground operations are considered, less equipment of all types and fewer man-hours are used to load, transport, and unload roof bolts and accessory materials than steel sets and accessory materials.

Suspension-roof-support materials have required much smaller storage areas than have been necessary for steel sets and lagging in the railroad yard, in the storage yards provided at each contract, and at all underground-storage locations.

CONCLUSIONS

Roof bolting in the East Delaware tunnel has protected the workers from roof falls and facilitated all phases of operations in the headings, thus increasing over-all efficiency. It has been the means of conserving many tons of steel, with resulting economies in both roof-support materials and the man-hours necessary to place them effectively.

Roof bolting on these contracts has provided safer working conditions and will have contributed greatly toward an early completion of the undertaking.

The success of suspension roof support in the East Delaware tunnel can be attributed to the following:

1. The participants in the venture logically solved the many local problems with which they were confronted with the advent of roof bolting.
2. Time, effort, and expense were not spared during the experimental phases.
3. Considered judgment was used in formulating suitable specifications.
4. Installations were supervised and inspected continuously.
5. Excellent cooperation was manifested by all concerned.

Consideration should be given these factors when roof bolting in a similar-type tunnel is planned.

Int. - Bu. of Mines, Pgh., Pa.